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Contract NAS9-4899

DESIGN OF AN ONBOARD CHECKOUT SYSTEM

FINAL REPORT

VOLUME I - SUMMARY

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Approved

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FOREWORD

This document is submitted in accordance with Task No. 4.9 of the Statement of Work Exhibit A, Contract NAS9-4899.

This document is submitted in three volumes:

Volume I - Summary;

Volume II - Technical Results;

Volume III - Implementation Plan.

CONTENTS

I. INTRODUCTION

The onboard checkout system (OCS) is a versatile test system applicable to any test and monitoring need. The design of an OCS was initiated through Contract NAS9-4899, dated 28 June 1965. The purpose of this task was to develop an independent, real-time system for preactivation verification and continuous monitoring of experimental and developmental subsystems for the Apollo applications program (AAP). The OCS will be used during both prelaunch and mission operations. The contract products are:

1) System design;

2) Feasibility breadboard;

3) System specifications;

4) Implementation plan.

An in-flight checkout and monitoring system is needed to ensure that experiments are in a state of operational readiness, validate experimental data, and provide a means of centrally managing mission experiments. An OCS will also be used to prove the feasibility of in-flight maintenance for future long-duration space missions.

Although based on the AAP, the OCS can be used with the Apollo experiments pallet (AEP) and any long-duration space mission such as MORL and Mars probes. An OCS ground version can be used for booster checkout. A portable version can perform experiment acceptance. In addition to checkout, the OCS can perform spacecraft subsystem control and housekeeping functions under astronaut control. The OCS also provides the basis for an efficient data management system.

The OCS system design uses a general-purpose digital computer for flexible control. A central stimulus generator provides a complete spectrum of electrical stimuli. A central measurement unit scales and digitizes signals for evaluation by the computer. A control and display system is used by astronauts and operators to manage experiments. Modular switching units distribute signals. A data interface and control unit converts data format among the airborne systems and ground systems such as ACE-S/C and MCC-H/GOSS. Modular packaging provides flexibility for various missions.

The software system design separates the test engineering task from the computer programing task. The test engineer describes tests to be conducted by simple test-oriented operations such as stimulate, measure, and compare. Any test can be described by combinations of a small number of such operations. The test descriptions are directly translated into airborne computer test data inputs without further programing. The test data inputs control a fixed set of subroutines that execute the standard test operations. Complex tests can be performed by appropriate combinations of operations from the small set of subroutines. Restricting computer programs to a small set of subroutines makes practical comprehensive testing to achieve software dependability.

A breadboard was built to demonstrate the feasibility of the OCS design concept. The breadboard performs each OCS hardware and software function in conjunction with a CDC 160A computer and simulated units under test. The breadboard was designed, built, and successfully demonstrated at MSC in less than 4 mo.

The OCS design met or exceeded all specifications established at the start of the study. Major characteristics of the AAP Phase I prototype OCS during a 14-day mission are:

1) Weight - 134 lb;
2) Power - 0.25 kwh/day;
3) Volume - 5040 cu in.;
4) Reliability - 0.998;
5) Tests - 640;
6) Memory - 12,000 words.

The OCS can be designed in 12 mo and delivered in 18 mo. Proven design techniques and proven component technology will be used throughout. The computer will be a flight-qualified machine that can be delivered in 10 mo. These system disciplines will exploit the reliability achievable with today's technology.

II. PROGRAM OBJECTIVES

The objectives of Contract NAS9-4899, Design of an Onboard Checkout System (OCS), have been to:

1) Analyze the requirements for an OCS, develop a breadboard OCS, and design a prototype OCS system for the Apollo applications program;

2) Develop hardware and software specifications and an implementation plan for the OCS.

III. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The method established to attain program objectives is illustrated in Fig. III-1. This method involves six activities:

1) Definition of OCS requirements;

2) Selection of a checkout concept;

3) Development of system design;

4) Development of breadboard feasibility model;

5) Documentation of technical results;

6) Development of an implementation plan for the follow-on program.

The principal assumptions that guided the OCS study were:

1) The OCS will demonstrate, by actual mission performance, the feasibility of onboard checkout during the Phase I AAP. The Phase II AAP configuration will be similar to the first-flight prototype, but with increased signal-handling capability;

2) During the Phase I AAP, each OCS will be delivered to the Kennedy Spacecraft Center (KSC) for installation in the spacecraft at the integration center. After installation, the OCS will function as an integral part of the total checkout system throughout the mission;

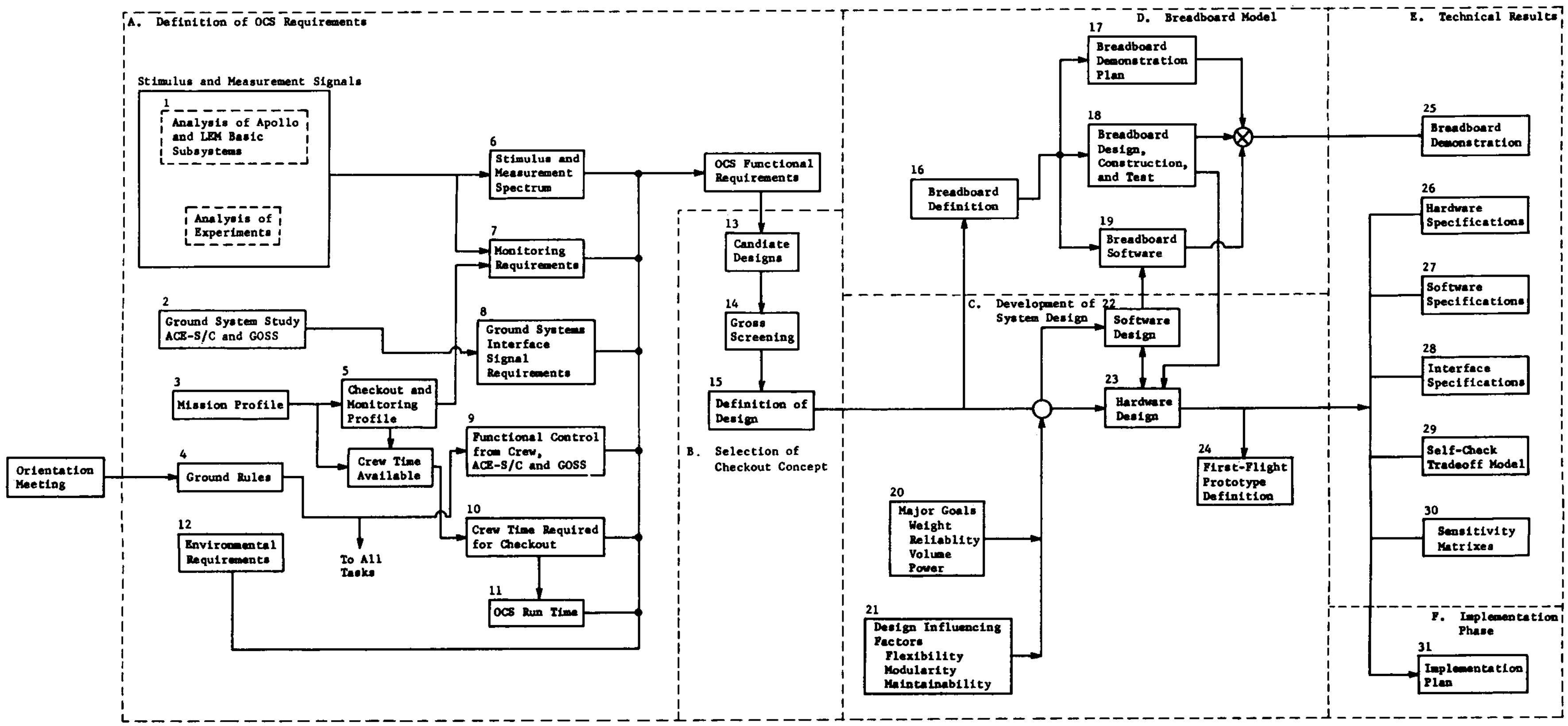

Fig. III-1 OCS Study Approach

3) Principal elements of the airborne OCS may be located in the command module (CM), service module (SM), lunar excursion module (LEM), or the AAP laboratory module. The exact location of OCS equipment will be determined by NASA-MSC and interequipment cabling will be provided by the spacecraft module contractor;

4) OCS ground support equipment (GSE) will interface with the airborne OCS through the acceptance checkout equipment-spacecraft (ACE-S/C) connection. OCS GSE will be located on the gantry and at the control center. ACE-S/C will be able to control OCS operations, OCS memory loading, and display of all test data;

5) The ground operational support system (GOSS) will be used as an interface link between the Mission Control Center-Houston (MCC-H) and the OCS. The GOSS interface with OCS will be through the Apollo command update link and the flight PCM;

6) The OCS will use modular construction to obtain configuration flexibility;

7) OCS design will use mature parts and materials to the maximum practical extent. The design will be based on use of an existing flight-qualified general-purpose digital computer;

8) There will be no in-flight maintenance. However, OCS will perform self-check to the replaceable module level. Ground maintenance will be based on replacing OCS units;

9) Basic power for OCS will be obtained from the spacecraft power system;

10) Flight crew training for the OCS will be integrated into the overall flight crew training program at NASA-MSC. Flight crew operation instructions will be incorporated in the Apollo Operations Handbook or its AAP equivalent.

IV. BASIC DESIGN SPECIFICATIONS GENERATED AND SIGNIFICANT RESULTS

Chapter II of this report has defined the basic design specifications generated. This chapter will summarize the functional intent of the specifications.

A. SPECIFICATION CP-180100, ONBOARD CHECKOUT SET - AIRBORNE (OCS-A/B)

1. General

A generalized functional block diagram of a checkout system is shown in Fig. IV-1. It contains a programing, decision, and sequencing function that sets up the test sequencing, contains the limits for testing, and controls the remaining portions of the system. The stimulus function inserts the excitation to force the unit under test into a particular operating state. The measurement function converts the response of the unit under test to the stimulus into a form usable by the decision portion of the system. The operator control and display provides the interface to the crew required for checkout operation. The external interface allows an external ground system to control and receive data from the checkout system.

2. System Operation

Figure IV-2 is a block diagram of the OCS-A/B for the AAP. It contains all of the elements shown in Fig. IV-1, but is drawn to show signal flow and the actual units or blackboxes that make up the system. All programing, sequencing, decisions, and test tolerances are stored in the computer memory. The computer and all other units of the system interface through a data interchange and control unit (DIACU). This unit handles all data formatting, routing, and signal-level conversion.

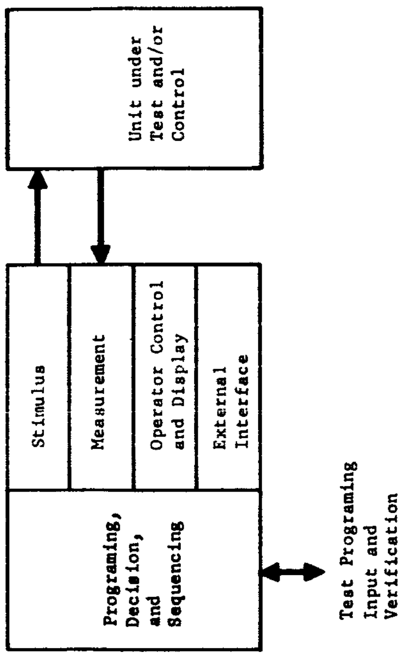

Fig. IV-1 Generalized Checkout System

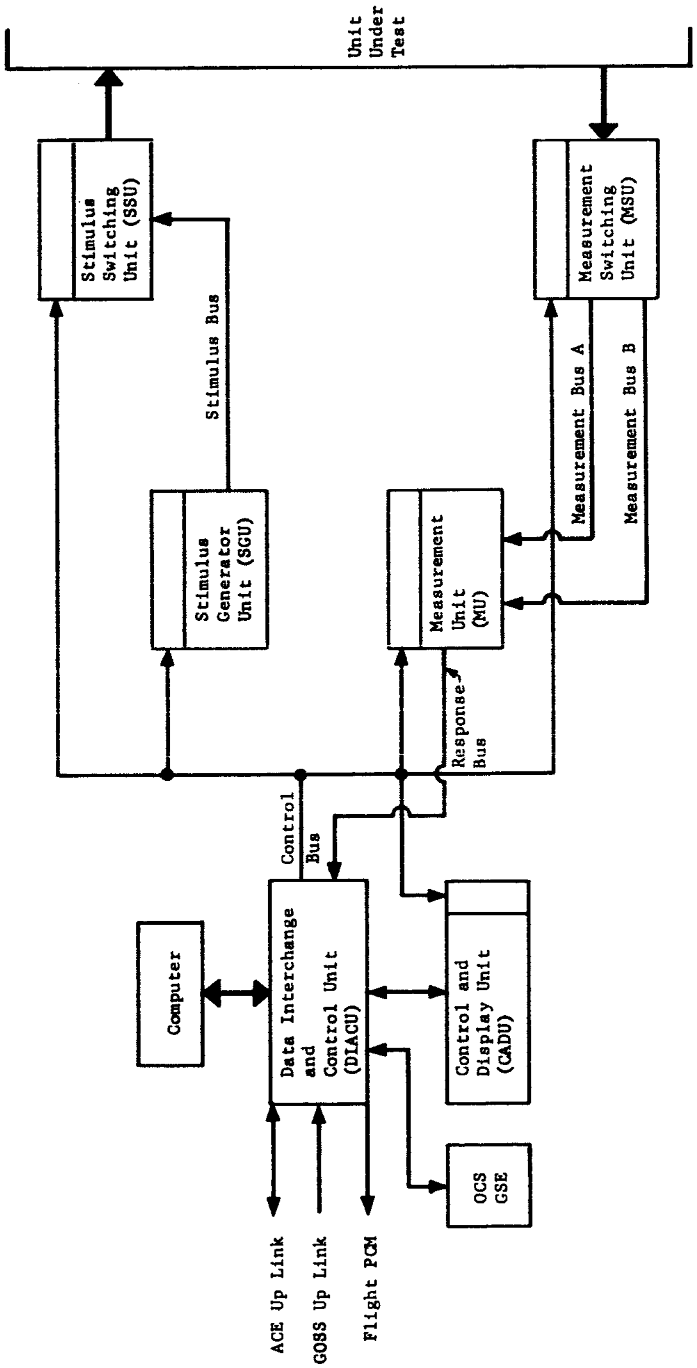

Fig. IV-2 Onboard Checkout System-Airborne

A command to perform a test or a series of tests may originate as the result of operator commands from the control and display panel onboard the spacecraft, from a control and display panel in the OCS-GSE, from the ACE-S/C during ground checkout, or from the GOSS worldwide communication net during flight. These commands will be sent by the DIACU to the computer by a parallel digital interface. The computer will interpret the command and will issue digital control data back to the DIACU. The DIACU will format the parallel data, perform level conversion, and send it out in serial form on the control bus. This single control bus is routed to all other units of the OCS as shown. A part of the data in the serial train is an OCS unit address. Each unit is designed so it will act only on the serial train if the data contain its address. The serial train is sent twice by the DIACU and each unit checks both transmissions before using the data. The result of the data check is sent back to the DIACU by the addressed unit. If the transmission check is bad, the complete cycle will be repeated several times. A normal test would proceed with a command to close a particular switch in a stimulus switching unit (SSU). The next command would be to the stimulus generator to supply a particular stimulus type and magnitude. The SGU would supply this stimulus on a single bus (stimulus bus) to the SSU. The SSU, already programed, would apply the stimulus to the particular point desired in the unit under test. Multiple lines interface the switching units with the unit under test. The MSU is then programed to connect a particular one of many test points to the analog measurement buses, A and B. Normally, only bus A is used. Bus B is needed for measurements requiring two lines such as phase, some time intervals, and modulated signals. The MU converts the analog data to a digital form and feeds it serially, along the response bus, to the DIACU. The DIACU again performs level conversion and sends the response data to the computer in parallel form. The computer then performs a decision based on prestored procedures. The sequence above is only typical. The order and time relationships of commands and data flow can be varied by programing. Stimulus and measurement capabilities are given in Tables IV-1 and IV-2.

Table IV-1 OCS-A/B Stimulus Characteristics

	Range	Tolerance (% of full scale)	Resolution	Distortion	Remarks
AC Voltage RMS	50 mv to 40 v (0 to 4 kc) into 400 Ωmin (3 ranges) 50 mv to 10 v (4 kc to 1 mc) into 50 Ω (3 ranges)	1.0	0.1% of Programed Value or 1 mv, Whichever is Greater	<1% to 100 kc <2% to 1 mc	Symmetrical about Ground ±1% p-p.
Frequency	0.1 cps to 1 mc in 7 ranges	1.0	0.1% of Programed Value		
Square Wave	0.1 cps to 1 mc in 7 ranges	1.0	0.1% of Programed Value	Overshoot and Ringing <5% for harmonics below 10 mc; <10% for Harmonics above 10 mc. Tilt <0.1%	Rise and fall time <0.1 μs. Amplitude same as for ac voltage.
DC Voltage	5 mv to 40 v into 400 Ωmin (4 ranges)	1.0	0.1% of Programed Value or 1 mv, Whichever is Greater		Ripple <0.1% of Programed Valve or 0.5 mv, Whichever is Greater
DC Current	1 to 300 ma into 30 Ωmax.	1.0	± 1 ma		
Voltage or Current Pulse	1 μsec to 10 msec 10 msec to 100 sec	1.0	±0.01% of Full Scale	Overshoot, Ringing and Tilt Same as for Square Wave	Amplitude same as for dc voltage or dc current.
Discretes	Supplied directly from discrete voltage buses in stimulus switching modules				

Table IV-2 OCS-A/B Measurement Characteristics

Measurement Type	Range	Accuracy	Resolution	Remarks
DC Voltage (Bipolar)	10 mv to 40 v	±1.0% of Value or Resolution, Whichever is Greater	500 μv	Frequencies: dc to 20 cps will be handled as a repetitive A/D conversion with magnitude determined by the computer to 1.0% accuracy
AC Voltage RMS	50 mv to 40 v (20 cps to 4 kc) 50 mv to 10 v (4 kc to 1 mc)	±1.0% of Value or Resolution, Whichever is Greater	1 mv	
Discretes (Bipolar)	2 to 32 v	±5%		
Contact Closures		Logic Decision		Discrete voltage provided to experiment by MSU
Time Time Interval Pulse Width Phase	1 μsec to 10 min	±0.1%	0.1 μsec	
Frequency	0.1 cps to 1.0 mcps	±0.1%		Magnitudes vary from 50 mvp to 40 vp
Pulse Code Modulation Word Length Bit Rate	 8 bits/word 40 bits/sec to 64K bits/sec	 ±1.0%		Decommutate data: select measurement words from 128 word serial pulse train knowing preassigned word positions
Digital Data				Systems under test that require measurement of a digital device will connect directly with the interface box through a single serial line. Any level conversion will be handled through a special adapter outside the interface
Suppressed Carrier Modulation	50 mv to 40 v	±1.0%	1 mv	Information frequency 0 to 20 cps. Carriers 100 cps to 10 kc. Measurement requirements are for in-phase component exclusive of quadrature and harmonics.

3. Operational Modes

a. Control

The system may be commanded to operate in an automatic, semiautomatic, or manual mode. In the automatic mode, a complete series of tests is commanded and, once enabled, proceeds until the last test desired is completed. An exception to this is that if a malfunction occurs on a test, a malfunction isolation set of tests may be run to isolate to a module or unit within the system being tested. After the malfunction tests are completed, the OCS will halt. The operator may restart the sequence if so allowed by the test program. The semiautomatic mode is similar to the automatic mode in that a series of tests (or a single test) is commanded. However, when enabled, the tests proceed one at a time. After each single test is completed, the next test is called up but will not be performed until the operator manually enables it. This allows the operator to go through a sequence of tests at his desired pace and view actual values of results as well as the go/no-go status. In the manual mode, the operator may construct a new test within program limits by defining the individual test elements of stimulate, measure, display, and compare and define the modifiers for each. Modifiers include such things as code number of test point to be stimulated; and type, frequency, duration, and magnitude of the stimulus. This newly generated test may be run once or may be made a permanent test and inserted as a test in a preestablished sequence.

b. Display

Regardless of where the command for a test sequence originates (spacecraft or ground), the same information relative to test results is returned to all operators. (Provided their control and display panel is receiving data, ACE-S/C and the OCS-GSE have no interface during flight and the spacecraft may not be within range of a T/M station during flight.) In the automatic mode, the operators get only the test sequence complete indication or, in the case of a no-go, the value of the no-go signal and the result of the malfunction isolation sequence. In the semiautomatic mode, the operators receive the actual value of response, with upper and lower limits in addition to the information received in the automatic mode. In the manual mode, the operator receives all data he enters into the computer during test construction to verify that the computer received the data intended.

4. Additional Functional Features

The system has two functional states. The first state is called standby. In this state, all power is turned off except that required for a timer and the circuits needed to bring it out of the standby state to an operating state. The system can be changed from standby to operating state by a programable timer or by a command from either the onboard control and display, the ACE-S/C, the GOSS, or a ground control and display that is a part of the OCS-GSE. Conversely, the system can be returned from operate to standby through the crew control and display, the GSE control and display, or when the computer has no further data to process.

In the operating state, the OCS can be in a checkout or monitor phase. The checkout phase has been explained. In the monitor phase, the system performs a passive monitoring function (no stimuli are issued). It scans a previously determined series of monitor points and compares them with limits and reports any out-of-limit condition. The time for this scan is on the order of a few seconds. The time between scans is programable up to 127 minutes by the operator or by the computer.

Provisions are included for OCS self-test, which enables malfunction isolation to the unit level and, in some cases, to modules within the units.

5. Design Features

Primary design features are:

1) Common program data bus;

2) Common response bus;

3) Common stimulus bus;

4) Common measurement signal bus;

5) Signal and return switching of all stimulus and measurement signals;

6) Transformer coupling of all data and power lines at each OCS unit;

7) Common power-enable bus;

8) Distributed power conditioner;

9) System modularity.

6. Physical Characteristics

At the beginning of the study, certain major goals were established. These preliminary goals, along with the achievable goals (if thin film circuitry is developed), are given in Table IV-3. The weight figure includes the weight of the expendables (H_2 and O_2) required by the fuel cell.

Table IV-3 Study Goals

	At Start of Study	At End of Study
Weight (lb)	150	147
Volume (cu ft)	Not assigned	3
Reliability (Based on 8-hr operation time in a 14-day mission)	0.9995 (Included onboard maintenance)	0.998 (Onboard maintenance not allowed)
Power (w)	1000	450
Availability (mo)	18	18

B. SPECIFICATION CP-181310 SOFTWARE - AIRBORNE, AND CP-181350 SOFTWARE - GROUND

Generation of an OCS test, from conception through execution, can be described as:

1) The test engineer prepares a test procedure in terms of the OCS test language. This language contains such terms as stimulate, measure, and display, together with appropriate modifiers;

2) The resulting test procedure is used directly to prepare a machine-readable form of the test;

3) The ground-based system, test language processor (TLP), translates the test procedure into a form acceptable by the aerospace computer. This process is chiefly that of data conversion and compacting. Error checks and language diagnostics are performed at this stage;

4) The resulting test description, on tape, is read into the aerospace computer and the loading is verified;

5) The tests are manipulated in one of several modes -- automatic, semiautomatic, and manual. Monitor tests are executed in the monitor phase;

6) Whatever the mode or phase, all tests are implemented by a set of subroutines called out by the test procedure description. These subroutines are executed sequentially in accordance with the test engineer's original description;

7) In the manual checkout mode, the local operator may construct or modify a test on-line. In this mode, the TLP is completely bypassed.

1. Test Language Processor (TLP)

The TLP is the portion of the software system that promotes efficient use and effective integration of many tests. In addition to the basic translation function, the TLP provides:

1) Test language diagnostics (checks on the completeness and accuracy of each test element and their order);

2) Complete printout of each test;

3) Checks on the stimulus point constraints -- magnitude, energy, and timing;

4) Machine-readable form of the required microdata unit data;

5) Memory allocation for each test and the software system;

6) Assignment list for switch points vs test points.

The last two items should be useful in sizing and developing the test complement for each mission.

2. Supervisory/Control Program

This programed system provides the sequencing control and internal operations necessary to implement the general system requirements. The following functions are performed:

1) Scheduling of tasks;

2) Control of test sequences in the several modes and phases;

3) Self-test;

4) Auditing, to ensure proper interpretation and execution of tests;

5) Service routines for input/output, special arithmetic, and display purposes.

Exercise of these programs depends on external control signals supplied by the local operator or via ACE or GOSS up-data links.

3. Test Elements

The checkout tests are implemented by a set of test element subroutines sequenced in accordance with the test engineer's description of the test procedure. The operator and the test engineer have access to these subroutines so they can construct or modify a test procedure. These test elements are designed to make the full capability of the OCS hardware available to these users. The functions provided include the following test-oriented operations:

1) Stimulate - analog signal;

2) Delay - await prescribed condition;

3) Measure - analog signal;

4) Latch - set and hold a discrete;

5) Sense - the state of an external discrete;

6) Switch - independent control of switches;

7) Processing - e.g., limit checks;

8) Action - next test, based on results of processing;

9) Display - results of test and descriptive material;

10) Transmit - status and data to remote operational center.

C. SPECIFICATION CP-180400 - GSE FOR OCS

The OCS-GSE has two major functions. The first is a duplicate of the control and display panel of the OCS-A/B as explained previously in Section A. The second function is to provide for memory loading of the OCS airborne computer. The memory loader interfaces with the DIACU at the same point as the ACE-S/C up-link.

D. SPECIFICATION IS-18000 - INTERFACE SPECIFICATION, OCS TO AAP EXPERIMENT AND DEVELOPMENTAL SUBSYSTEMS

This specification defines the OCS in a form to be used by experiment and developmental subsystem manufacturers. It describes system operation and capabilities to allow the design of these systems and their test requirements to be compatible with OCS.

E. SPECIFICATION IS-180A50 - INTERFACE SPECIFICATION, OCS TO AAP LABORATORY

This specification defines the installation and functional interfaces between OCS and the AAP laboratory in which OCS is installed. These interfaces include mechanical, thermal, power, cabling, the command up data link and the PCM telemetry down link.

F. SPECIFICATION IS-180B60 - INTERFACE SPECIFICATION, OCS TO ACE-S/C

ACE-S/C interfaces with OCS at the 1-mc serial input to the ACE-S/C receiver decoder. This input is fed to the DIACU of the OCS. ACE-S/C receives down-link information over the existing flight PCM. Functional control interfaces were previously described in Section A. The OCS computer memory can be loaded through ACE.

G. SPECIFICATION IS-180C70 - INTERFACE SPECIFICATION, OCS TO MCC-H/GOSS

The MCC-H/GOSS interfaces with OCS via the UDL A/B decoder for up link and via the flight PCM for down link. Functional control interfaces were previously described in Section A.

H. FEASIBILITY BREADBOARD

A breadboard was produced to show the feasibility of the selected OCS concept. It contains, in abbreviated form, most of the functional features discussed in Section A. It consists of a display board, which graphically shows OCS operation. Functional hardware is mounted in a cabinet underneath the display board. It contains a stimulus unit, measurement unit, switching units, and an abbreviated DIACU. The control and display panel is mounted on the display board mentioned above. The breadboard software also contains, to a limited degree, the major capabilities of the final system software.

V. PROGRAM LIMITATIONS

A summary of the OCS development and test program schedule is shown in Fig. V-1. This program is based on 1 July 1966 go-ahead, an initial launch in July 1968, and delivery of the flight unit to the site 3 mo before month of launch.

The following factors are critical to achieving program schedules:

1) The critical path includes the thin film design, development, and evaluation;

2) The packaging configuration must be established 3 mo ahead of complete system definition;

3) The engineering development unit will, in many cases, be built from materials and components available from current programs, since the procurement cycle is not compatible with the early program needs;

4) A breadboard computer of limited capability is needed soon to develop OCS software and to identify interface requirements;

5) Flight certification will be accomplished before shipment of the first flight article and qualification will be complete before the first launch.

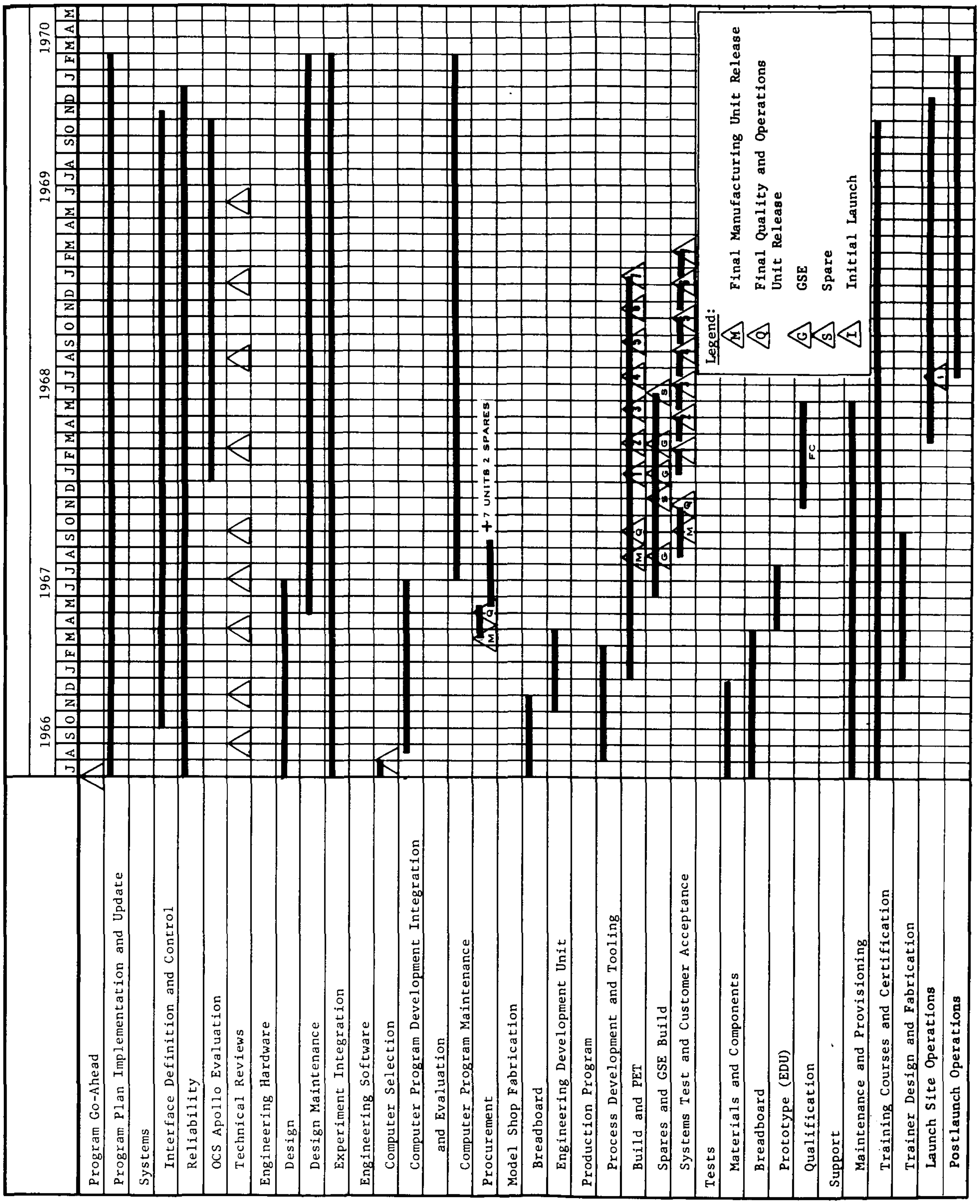

Fig. V-1 Summary Onboard Checkout System Developmental Program Schedule

VI. RELATIONSHIP TO OTHER NASA EFFORTS

The OCS has two general applications to other NASA programs: first, as a checkout system, and, second, as a system for data management and system control.

The OCS was designed for use in the AAP as a ground and airborne checkout system. It could also be used as a checkout system in the AEP program and any long-duration manned space vehicle such as MORL and Mars probes. At some time in the future, flight duration and reliability requirements will dictate in-flight maintenance that, in turn, will demand an OCS.

The OCS design concept could be implemented in a ground version. The ground version would be a general-purpose checkout system. It could then be used for booster and spacecraft checkout. This usage could replace test tooling or avoid purchase of new, special-purpose GSE. An interesting application for a ground version of OCS would be as a portable experiment acceptance tool. This tool would have significant cost advantages over separate tooling for each experiment when used throughout the entire Apollo experiments program.

The elements of the OCS are an excellent beginning for system control functions and data management. Since systems must be exercised during checkout, the elements for control are already present in the OCS. The OCS could control experiments and developmental subsystems on both AAP and AEP. Data management systems perform many of the same functions as the OCS. The only significant element to be added to the first-flight prototype OCS to accomplish data management is a more versatile memory such as a tape recorder. The switching and measurement units can gather, scale, and digitize analog data. The tape unit would record and play back the data. The DIACU can provide format changes. The computer can control the entire process.

VII. IMPLICATIONS FOR RESEARCH

Thin Film - Thin film circuitry is relatively new in the electronics field. Research is required to determine the true reliability of these circuits.

Microdata Unit - The control and display panel contains a microdata unit. The unit is a back-lighted film projection system that supplies the crew with a variety of test information. In effect, it replaces a handbook. The optics of the unit require some research to get the unit to an acceptable size and weight.

Control and Display Unit - Crew interface studies are needed to determine the optimum man/machine interface.

VIII. SUGGESTED ADDITIONAL EFFORT

During the OCS study, a number of subjects were noted that would benefit from additional study. The recommended additional studies include:

1) Man-machine interface needs thorough study to answer these questions: Are the functions assigned to the astronaut too complex? Can the astronaut be taught to perform as a test engineer/programer? Are the planned astronaut control capabilities really required for effective performance of experiments? Are the human engineering aspects of the control panel adequate? Where is the crossover between use of microdata display and a handbook?

2) Experiment and developmental subsystem requirements analysis should be continued. This would emphasize two problems: Is the signal spectrum planned for OCS still compatible with the actual requirements? Can a narrower range of signal interfaces between the OCS and the experiments and developmental subsystems be established?

3) MCC-H/GOSS and ACE-S/C interfaces with OCS need further study. Emphasis would be placed on the following questions: How does an operator execute an OCS control function through each system? How would MCC-H/GOSS transmit an OCS command? What is the coding for OCS down-link reporting?

7) Computer selection is extremely critical to timely completion of the OCS development program. The computer is a central factor in system design; therefore, many design decisions must be tentative until a computer is selected. Further, a breadboard computer is needed soon after go-ahead so software development can proceed.

5) Control and display unit design must be extended to confirm characteristics. What are the physical characteristics of the microdata unit? What are the recommended control and display devices?

6) Functional analysis should be completed to ensure that all resources required to support OCS have been identified. For example, what are the common tools required for maintenance?